Chapter 12

Defining Reservoir Systems

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Chapter 12

Defining Reservoir Systems

Reservoir systems are created by defining system operation rules for two or more reservoirs. ResSim provides for tandem operation to manage the storage distribution between upstream and downstream reservoirs on the same stream. Tandem operations are created by applying a tandem rule at an upstream reservoir operating for a downstream reservoir (e.g., reservoirs in series). In addition, ResSim supports parallel operation of reservoirs, where two or more reservoirs on different streams control for common downstream requirements, through the use of common downstream control (for flow or stage limit) rules. For each individual reservoir, system operation rules are prioritized among other rules in the operation set (refer to Chapter 11, Section 11.4.5 for a more detailed description of rule prioritization). This chapter will present the concept of system operation, specifically implicit and explicit methods for determining the system balance, and provide guidance for using the Reservoir System Editor to set up explicit system storage balances.

12.1 Concept of Reservoir Systems

When a tandem or parallel reservoir system is defined, the model determines the priority and the amount of release to make from each reservoir in order to operate towards a storage balance. For every decision interval, an end-of-period storage is first estimated for each reservoir based on the sum of beginning-of-period storage and period average inflow volume, minus all potential outflow volumes. The estimated end-of-period storage for each reservoir is compared to a desired storage that is determined by using a system storage balance scheme. The priority for release is then given to the reservoir that is *farthest above* the desired storage. When a final release decision is made, the end-of-period storages are recomputed. Depending on other constraints or higher priority rules (see Chapter 11), system operation strives for a storage balance such that the reservoirs have either reached their Guide Curves or they are operating at the **desired storage** (percent of the active storage zone).

There are two methods by which the desired storage balance is determined: implicit (default) and explicit (user-defined). The implicit method delineates the *default* storage balance scheme for the reservoir system. The explicit method is optional and allows a *user defined* storage balance scheme for the reservoir system. Detailed descriptions and examples are presented in Sections 12.1.1 and 12.1.2 for demonstrating the functionality of implicit and explicit storage balance methods.

12.1.1 Implicit System Storage Balance Method

The *default* method in ResSim for determining the desired storage balance in a reservoir system is referred to as the *implicit* method. This method applies to both tandem and parallel system operations. The implicit method is automatically used when a reservoir system is established − either by using a common **Downstream Control** rule in two or more parallel reservoirs, or adding a **Tandem Operation** rule to an upstream reservoir operating for a downstream reservoir.

For example, consider a two-reservoir tandem system, as shown in Figure 12.1. Reservoir 1 is the upstream reservoir where a **Tandem Operation** rule has been applied in its operation set, as shown in Figure 12.2 (see Section 11.5.5 for details about adding the Tandem Operation rule). This establishes an implicit system operation with the downstream reservoir, Reservoir 2. Assume that each reservoir has the same amount of storage capacity (100,000 ac-ft). For each of the reservoirs, the Guide Curve has been set to be the top of Conservation zone (see Section 11.8 for instructions on setting the Guide Curve). The conservation storage in Reservoir 1 is 75,000 ac-ft, whereas the conservation storage in Reservoir 2 is 30,000 ac-ft.

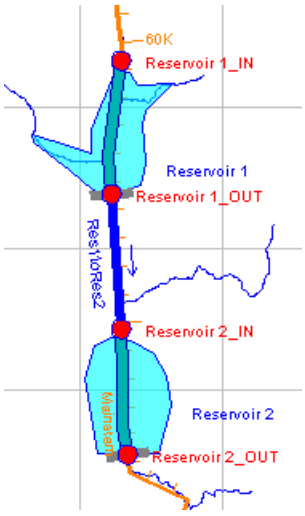

Figure 12.1 Example of a Two-Reservoir Tandem System

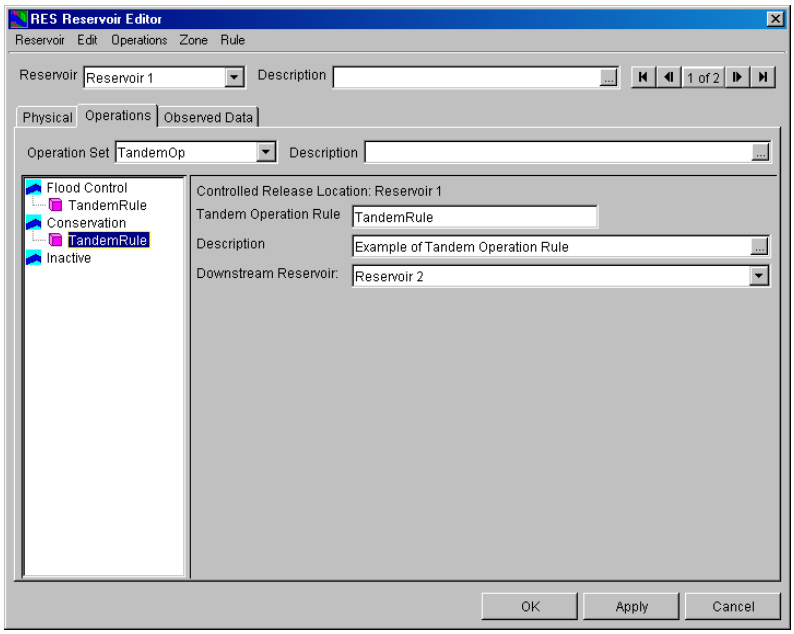

Figure 12.2 Tandem Operation Rule Included for Reservoir 1

The implicit system storage balance scheme (illustrated in Figure 12.3) takes into account the **System Storage** (the total storage from the reservoirs in the system). In this example, the system storage ranges from empty (0 ac-ft) to full (200,000 ac-ft). Additionally, this default scheme considers only one **System Zone**, the System Guide Curve (Sys G.C.) storage, which amounts to the sum of both reservoirs' conservation storages (105,000 ac-ft).

The **desired storage** for each reservoir is determined through an implicit "balance line". The balance line is simply a linear relationship between storage at each reservoir and the system storage. For each reservoir, the balance line hinges on the intersection of the reservoir's Guide Curve (G.C.) storage and the System Guide Curve (Sys G.C.) storage. For system storage *less than* the System Guide Curve storage, the balance line has a lower limit that corresponds to empty storage at the reservoir versus empty system storage, and the upper limit corresponds to Guide Curve storage at the reservoir (75,000 ac-ft at Res. 1 and 30,000 ac-ft at Res. 2) versus System Guide Curve storage (105,000 ac-ft). For system storage *greater than* the System Guide Curve storage, the lower limit of the balance line corresponds to Guide Curve storage at the reservoir (75,000 ac-ft at Res. 1 and 30,000 ac-ft at Res. 2) versus System Guide Curve storage (105,000 ac-ft), and the upper limit corresponds to full storage at the reservoir versus full system storage.

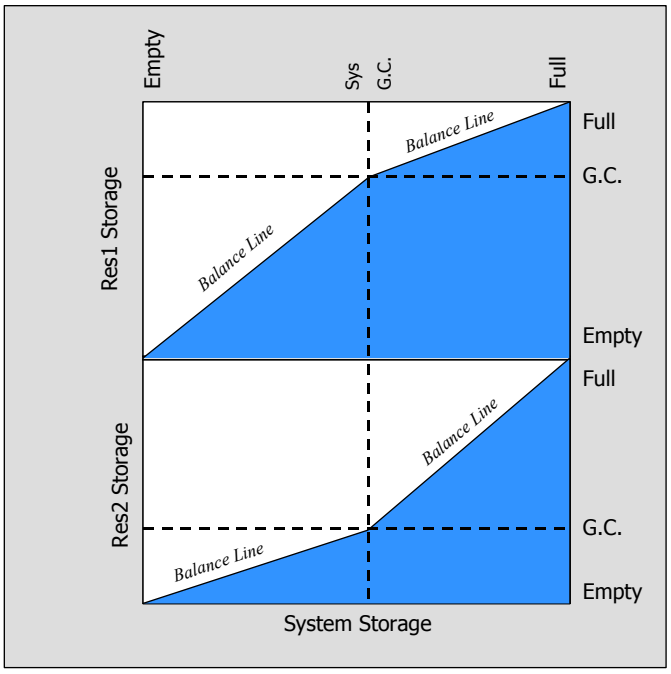

Figure 12.3 Implicit System Storage Balance

At the end of each decision interval (i.e., end-of-period), the **desired storage** for a reservoir corresponds to a point on the balance line that coincides with the sum of the estimated storages for both reservoirs. When the total estimated storage from both reservoirs is *less than* the System Guide Curve storage, the corresponding desired storages represent an equal percentage of the storage *below* the Guide Curve at each reservoir. When the total estimated storage from both reservoirs is *greater than* the System Guide Curve storage, the corresponding desired storages represent an equal percentage of the storage *above* the Guide Curve at each reservoir.

For instance, as shown in Figure 12.4, assume that preliminary end-of-period storage estimates are 25,000 ac-ft for Reservoir 1 and 45,000 ac-ft for Reservoir 2. The resultant total system storage of 70,000 ac-ft coincides with each reservoir's desired storage (50,000 ac-ft for Reservoir 1 and 20,000 ac-ft for Reservoir 2) found along the balance line from empty system storage to System Guide Curve storage. These desired storage values signify a desired balance because they amount to an equal 66.7 percent of the Guide Curve storage at each reservoir: 50,000 of 75,000 ac-ft at Reservoir 1, and 20,000 of 30,000 ac-ft at Reservoir 2.

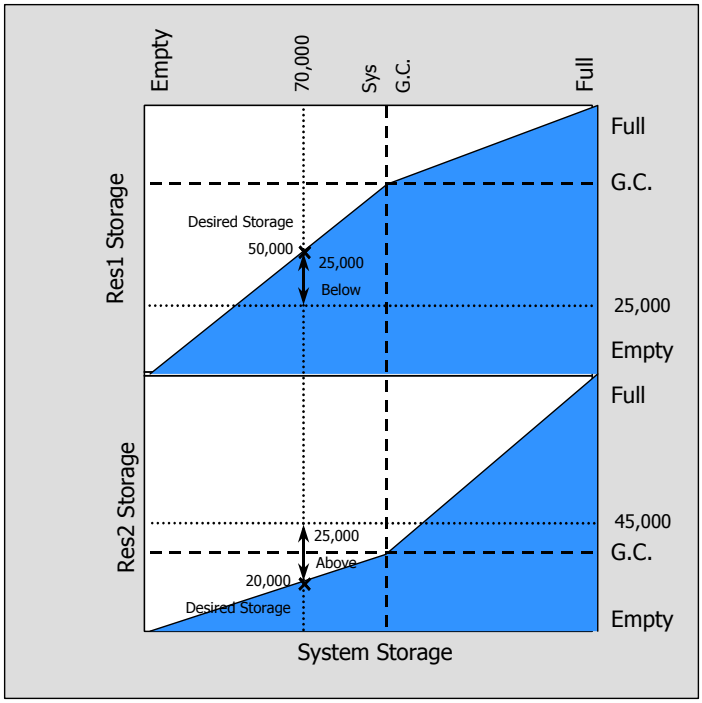

Figure 12.4 Example of Desired Storages using the Implicit System Storage Balance Method

With 25,000 ac-ft estimated as its end-of-period storage, Reservoir 1 would be below its desired storage of 50,000 ac-ft. On the other hand, at an estimated storage of 45,000 ac-ft, Reservoir 2 would be above its desired storage of 20,000 ac-ft.

Since Reservoir 2 is above its desired storage, it receives the priority to release for this period in order to drop its storage down, as close as possible, to the desired storage. Unless other constraints (such as maximum physical outlet capacity, maximum flow limit rules, or flow rate of change limit rules) restrict releases and have higher priority than the system operation rule, Reservoir 2 would increase its releases in order to drop its pool to the desired storage of 20,000 ac-ft. As for Reservoir 1, it is forced to cut back its releases so that its storage can rise, as close as possible, to its desired storage of 50,000 ac-ft. If there are no restrictions (such as minimum flow limit rules or flow rate of change limit rules) that could require a different release due to having a higher priority than the system operation rule, Reservoir 1 would stop releasing from its outlet(s).

In the implicit system operation, a release decision made for a particular time period may not necessarily achieve the desired balance. The reservoirs in the system are considered "in balance" when both reservoirs have reached their Guide Curves, or they are operating at equivalent storage levels in terms of percentage of their counterpart system storage zones.

12.1.2 Explicit System Storage Balance Method

The *user-defined* method in ResSim for determining the desired storage balance in a reservoir system is referred to as the *explicit* method. This method can be used for an established reservoir system, whether tandem or parallel.

For example, consider two parallel reservoirs (Reservoir 1 and Reservoir 2) operating for a common downstream location (MyTown), as shown in Figure 12.5. In this case, both reservoirs are operating for a common downstream location, and each has the same downstream control rule applied in its operation set (establishing an implicit system operation). As described in Section 12.1.1, the implicit scheme by default develops balance lines, using a single system storage zone (System Guide Curve), to define linear relationships between storage at each reservoir and the total system storage. The

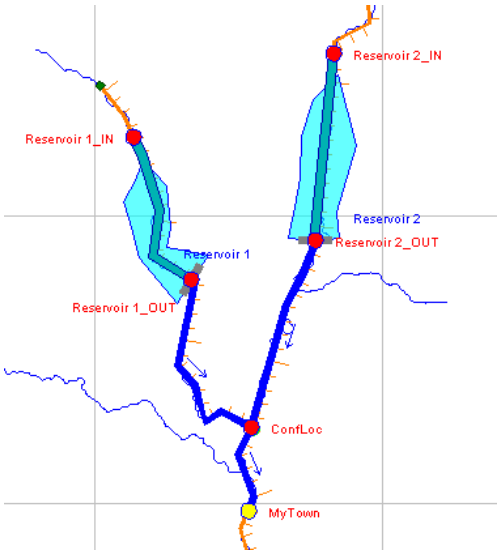

Figure 12.5 Example of a Two-Reservoir Parallel System

user can further modify these balance lines explicitly to characterize the desired storage distributions using one or more system zones and placing inflection points along the balance line.

For this example, both reservoirs have the same storage characteristics, maximum storage capacities and conservation storage as described in the tandem example in Section 12.1.1. Additionally, for Reservoir 1, the top of the Flood Control zone is at a storage of 85,000 ac-ft. For Reservoir 2, the top of Flood Control is at a storage of 65,000 ac-ft.

Figure 12.6 shows an explicit scheme defined such that Reservoir 1 fills up its conservation zone before Reservoir 2, and Reservoir 2 fills up its flood control zone sooner than Reservoir 1. This is accomplished by first identifying two system zones. For instance, System Conservation would represent one system zone that is the aggregate of the conservation storages from the two reservoirs. The other system zone would be the System Flood Control zone, the total of both reservoirs' flood control storages. As shown in Figure 12.6 and summarized in Table 12.1, a customized desired storage balance can be made by introducing inflection points to the balance lines within each system zone. Inflection points would transform the implicit balance line into an explicit curve. An unlimited number of balance line inflection points could be added within each system zone to further refine and shape the desired balance distribution.

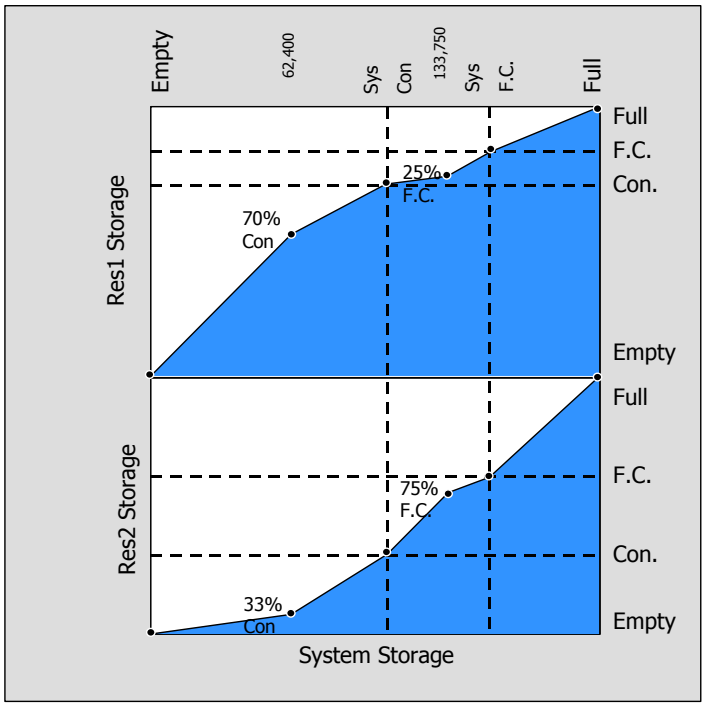

Figure 12.6 Explicit System Storage Balance

Table 12.1 Explicit System Storage Balance

Storage	Reservoir 1	Reservoir 2	System Storage
Full	100,000 ac-ft	100,000 ac-ft	200,000 ac-ft
F.C.	85,000 ac-ft	65,000 ac-ft	150,000 ac-ft
%F.C.	*(25% F.C.)* *77,500* ac-ft	*(75% F.C.)* *56,250* ac-ft	*133,750 ac-ft*
Con	75,000 ac-ft	30,000 ac-ft	105,000 ac-ft
%Con	*(70% Con)* *52,500* ac-ft	*(33% Con)* *9,900* ac-ft	*62,400* ac-ft
Empty	0 ac-ft	0 ac-ft	0 ac-ft

In this example, within the System Conservation zone, balance line inflection points are set at 70 percent of the conservation storage (52,500 ac-ft) for Reservoir 1 and 33 percent of the conservation storage (9,900 ac-ft) for Reservoir 2. As a result, these inflection points coincide with system storage of 62,400 ac-ft, and reshape their respective balance line curves according to the general criterion that Reservoir 1 fills up its conservation zone before Reservoir 2. Similarly within the Flood Control System zone, balance line inflection points set at 25 percent of the flood control storage (77,500 ac-ft) for Reservoir 1 and at 75 percent of the flood control storage (56,250 ac-ft) for Reservoir 2 coincide with system storage of 133,750 ac-ft. This would satisfy the requirement that Reservoir 2 fills up its flood control zone sooner than Reservoir 1.

As demonstrated in Figure 12.7, for estimated end-of-period storages of 25,000 ac-ft at Reservoir 1 and 45,000 ac-ft at Reservoir 2, the resultant system storage of 70,000 ac-ft coincides with desired storages found along the explicitly defined balance line curves within the System Guide Curve storage zone. The desired storage levels are 56,500 ac-ft for Reservoir 1 and 13,500 ac-ft for Reservoir 2.

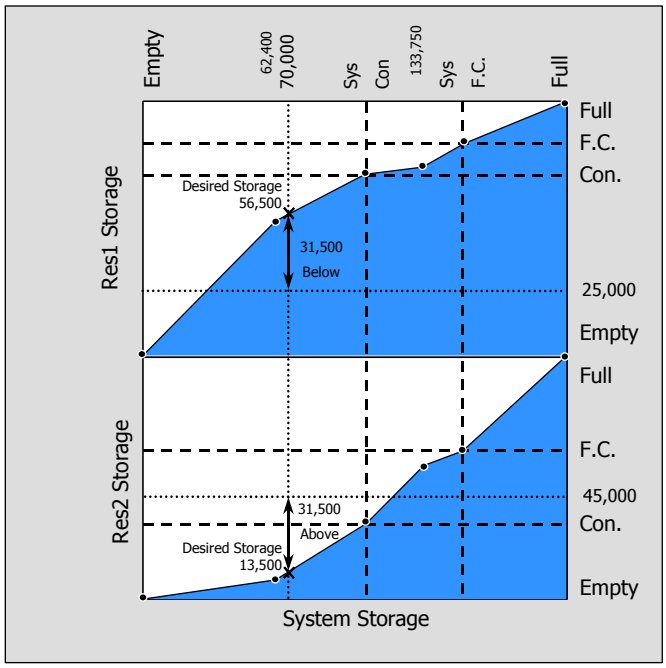

Figure 12.7 Example of Desired Storages using the Explicit System Storage Balance Method

At 45,000 ac-ft, Reservoir 2 would be above its desired storage of 13,500 ac-ft. As such, Reservoir 2 receives the priority to release for this period. Unless other constraints restrict releases and have higher priority than the system operation rule, Reservoir 2 would increase its releases in order to reduce its storage, as close as possible, to the desired storage. On the other hand, with only 25,000 ac-ft of estimated storage, Reservoir 1 would be below its desired storage of 56,500 ac-ft. Then Reservoir 1 is forced to cut back its releases for this particular time period so that its storage can rise, as close as possible, to the desired level. If there are no higher priority rules that require a release, Reservoir 1 would not make a release from its outlet(s).

Similar to the implicit system operation, the explicit system operation is carried out each time period when system rules are in effect. The process of determining desired storages is repeated every decision interval in order to assign the priority for release to the reservoir that is farthest above the desired storage. A release decision made for a particular time period may not necessarily achieve the desired balance. The reservoirs are considered "in balance" when both reservoirs have reached their Guide Curves or are operating at the desired storages levels along their balance line curves as prescribed in the explicit storage balance scheme.

The user interface process of creating an explicit system storage balance is described in subsequent sections.

12.2 Overview of the Reservoir System Editor

The **Reservoir System Editor** is used to create explicit system storage balances for selected reservoir systems. The editor is very similar to the **Operations** tab of the **Reservoir Editor** (see Chapter 11, Section 11.1). An example of the **Reservoir System Editor** is shown in Figure 12.8 and reflects the example data for the explicit storage balance method previously discussed in Section 12.1.2.

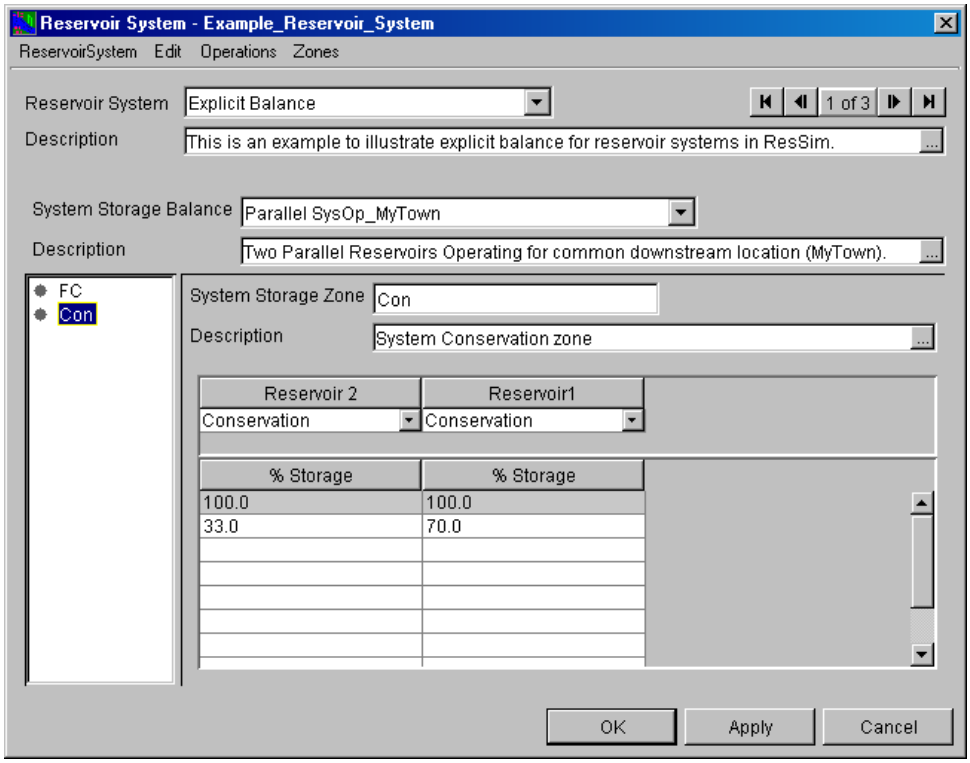

Figure 12.8 Reservoir System Editor (New Reservoir System)

As previously discussed, a reservoir system is implicitly created when two or more reservoirs are operating in tandem or when parallel reservoirs are operating together for a common downstream location. For system operations, you can either accept the implicit default system storage balance or you can create and define one or more explicit **System Storage Balance** schemes. For each system storage balance scheme you develop, you must define the **System Storage Zones** and the distribution of storage across the individual reservoirs (similar to the concept of **Reservoir Operation** sets discussed in Chapter 11, Section 11.2).

The remainder of this chapter will discuss the **Reservoir System Editor** in detail and will provide instructions for specifying explicit system storage balance data.

12.3 Accessing the Reservoir System Editor

To specify the explicit reservoir system balance scheme, you will use the **Reservoir System Editor** (previously shown in Figure 12.8). This editor is available in the **Reservoir Network Module** and is accessed from the **Edit** menu (in the menu bar), as shown in Figure 12.9.

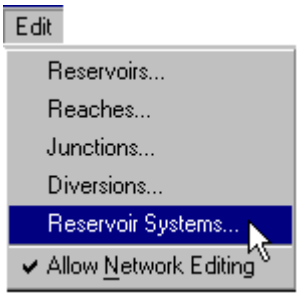

Figure 12.9 Reservoir Network Module, Edit Menu, Reservoir Systems

12.4 Reservoir System Editor Menu Items

At the top of the **Reservoir System Editor**, the **Menu Bar** includes four menus unique to this editor. The menus are **ReservoirSystem**, **Edit**, **Operations**, and **Zones**. These menus provide the following options: creating, renaming and deleting reservoir systems; editing reservoir sets; creating, renaming and deleting system operation sets; and, creating and deleting system zones. These options are presented in the following paragraphs and described in subsequent sections of this chapter.

The **ReservoirSystem** menu (Figure 12.10) allows you to create a **New** system, **Rename** a system, **Delete** a system, and **Close** the editor. Refer to Section 12.5 for additional information.

Figure 12.10 Reservoir System Editor, ReservoirSystem Menu

From the **Edit** menu (Figure 12.11), select **Edit Reservoir Set** to specify which reservoirs are to be included in the reservoir system.

Figure 12.11 Reservoir System Editor, Edit Menu

The **Operations** menu (Figure 12.12) allows you to create a **New** system operation set, **Rename** a system operation set, or **Delete** a system operation set.

Figure 12.12 Reservoir System Editor, Operations Menu

The **Zones** menu (Figure 12.13) allows you to create **New** system zones or **Delete** system zones and is active only after a system operation set has been created.

Figure 12.13 Reservoir System Editor, Zones Menu

12.5 Defining a New Reservoir System

The **Reservoir System Editor** is used for creating a Reservoir System with explicit system storage balances. The process of setting up a new reservoir system includes defining a new reservoir system, creating a system operation set (see Section 12.7), defining system zone values (see Section 12.8), and specifying the storage balance (see Section 12.9) for each reservoir in your system.

The initial steps in creating a reservoir system that uses explicit system storage balancing are:

1. From the **ReservoirSystem** menu, select **New System**. The **New Reservoir System** dialog box will open (Figure 12.14).

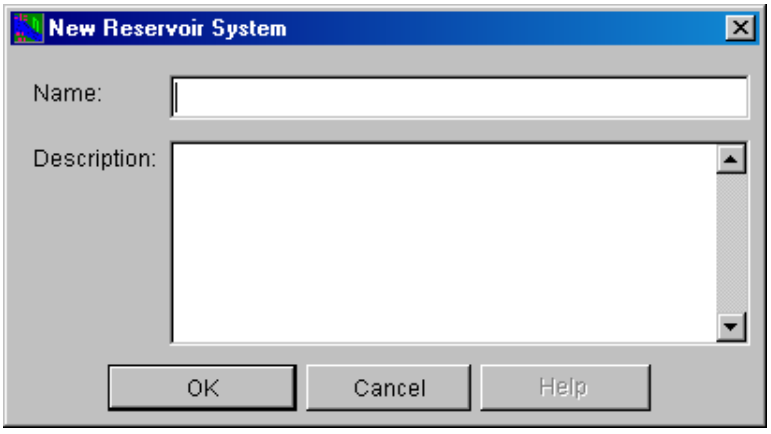

Figure 12.14 New Reservoir System Dialog Box

2. Enter a **Name** and **Description** for the new reservoir system.
3. Click **OK**. The **New Reservoir System** dialog will close.

The name and description of the new **Reservoir System** will now appear in the **Reservoir System Editor**, with all other fields remaining blank (as shown in Figure 12.15).

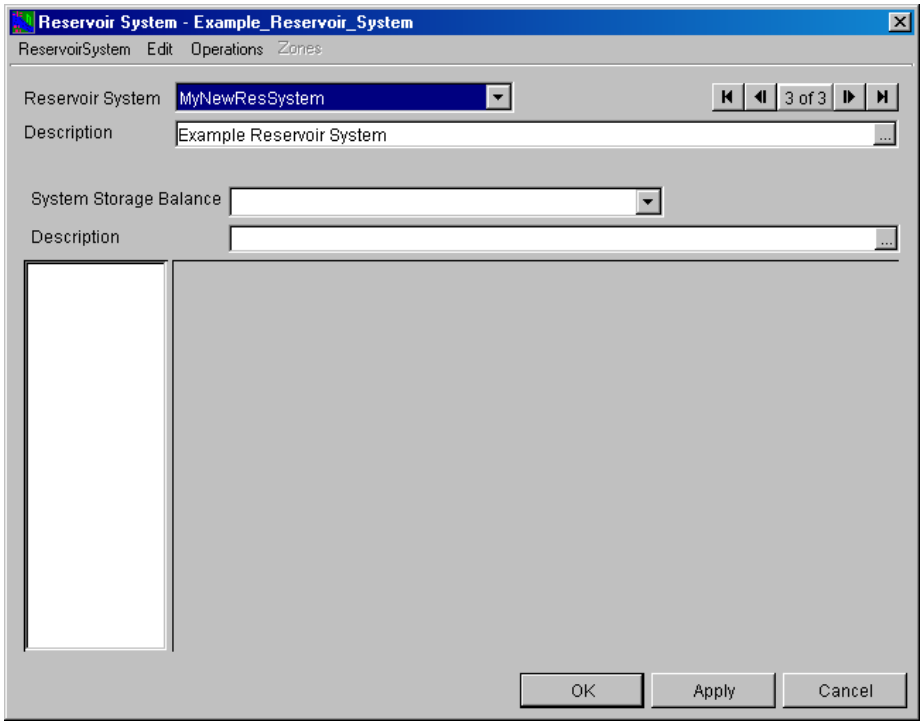

Figure 12.15 Reservoir System Editor (New Reservoir System)

12.6 Selecting Reservoirs for the System

Once you have named your reservoir system, you will need to select all of the reservoirs to be included in the system storage balancing. *Only those reservoirs that have not been included in another reservoir system are available to be selected.*

To select the reservoirs to be included in the system storage balancing:

1. Choose **Edit Reservoir Set** from the **Edit** menu of the Reservoir System Editor. The **Reservoir Selection Editor** will open (Figure 12.16).
2. The available reservoirs in your network (that have not been included in another reservoir system) appear in the **Available** pane on the left side of the **Reservoir Selection Editor**. To add a reservoir to your new reservoir system, click on the reservoir's name and click the **Add** button. To select all of the available reservoirs, click the **Add All** button.
3. The reservoirs you select will move from the **Available** pane to the **Selected** pane on the right. To remove a reservoir from the selected list, click on its name and click the **Remove** button. To remove all reservoirs from the **Selected** list, click the **Remove All** button.

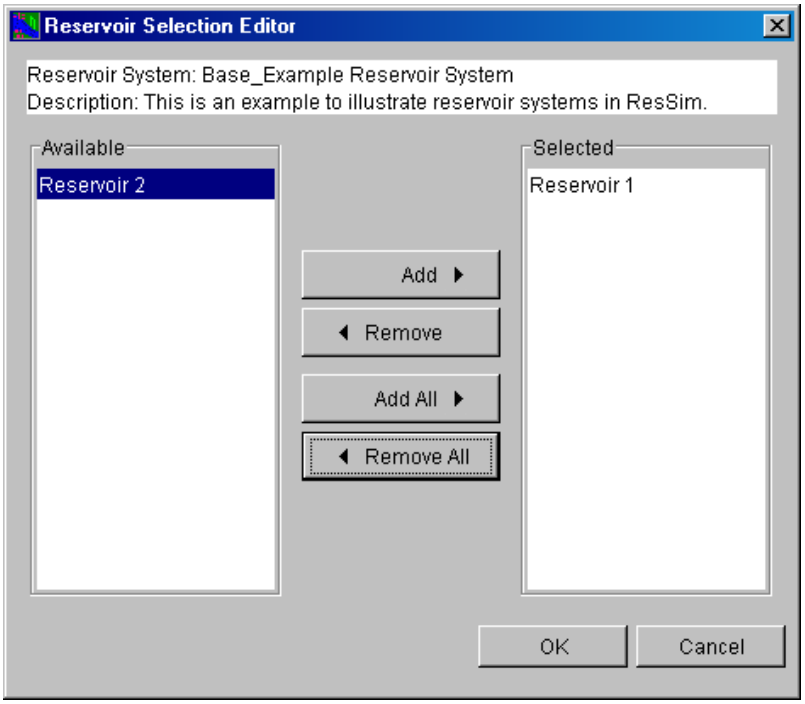

Figure 12.16 Reservoir Selection Editor

4. Click **OK** to approve your choices and close the **Reservoir Selection Editor**.

Although you have selected reservoirs for your reservoir system, they will not yet appear in the **Reservoir System Editor**. You must first specify the system storage balance and define reservoir system storage zones.

12.7 Defining a System Storage Balance Operation Set

To define the **System Storage Balance Operation Set** for the reservoirs in your reservoir system:

1. Select **New** from the **Operations** menu of the **Reservoir System Editor**. The **New Operation Set** dialog box will open (Figure 12.17).

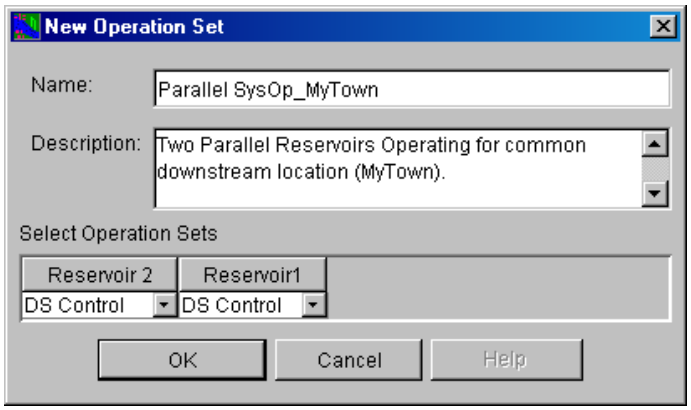

Figure 12.17 New System Storage Balance Operation Set for Reservoir System

2. Enter **a Name** and **Description** for the **System Storage Balance Operation Set**.
3. Below the **Description** area, you will see the names of the reservoirs you have selected for your system. The white box below the name of each reservoir contains a list of the **Operation Sets** available for that reservoir. Double-click on the white box to access the list for each reservoir and then select an operation set that *contains the system operation rule(s)*.
4. Click **OK** to close the New Operation Set dialog box.

Note that your changes will not yet appear in the **Reservoir System Editor**. You must first define at least one **Reservoir System Zone**.

12.8 Defining Reservoir System Zones

To define the **Reservoir System Zone**(s):

1. Select **New** from the **Zones** menu of the **Reservoir System Editor**. The **New Storage Zone** dialog box will open (Figure 12.18)

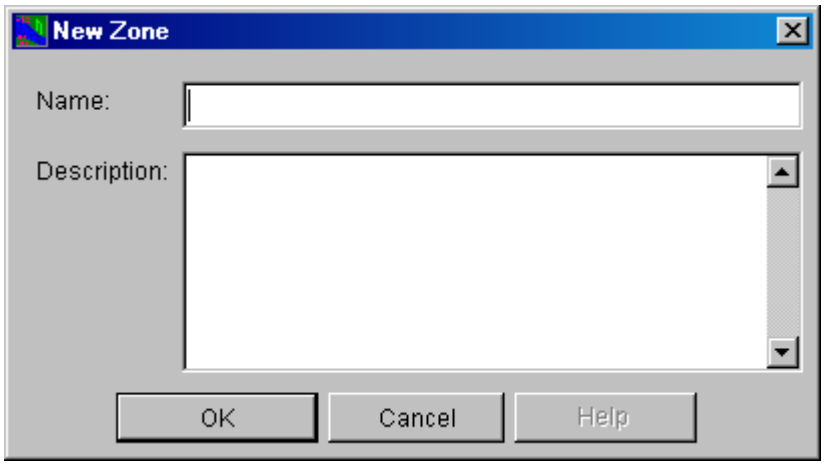

Figure 12.18 New Storage Zone Dialog Box

2. Enter a **Name** and **Description** for the new storage zone.
3. Click **OK** to close the **New Storage Zone** dialog box.

When you have defined at least one system storage zone for your reservoir system, its name will appear in the white pane at the bottom left of the **Reservoir System Editor**, and a new set of fields will appear in the large gray area, as shown in Figure 12.19. These new fields allow you to configure the system storage balance for your reservoir system.

12.9 Configuring System Storage Balance

Once you have successfully created a new reservoir system (by following the steps presented in Sections 12.5 through 12.8), several new fields become available that allow you to configure the storage balance across reservoirs. We will use Figure 12.19 to illustrate how to do this.

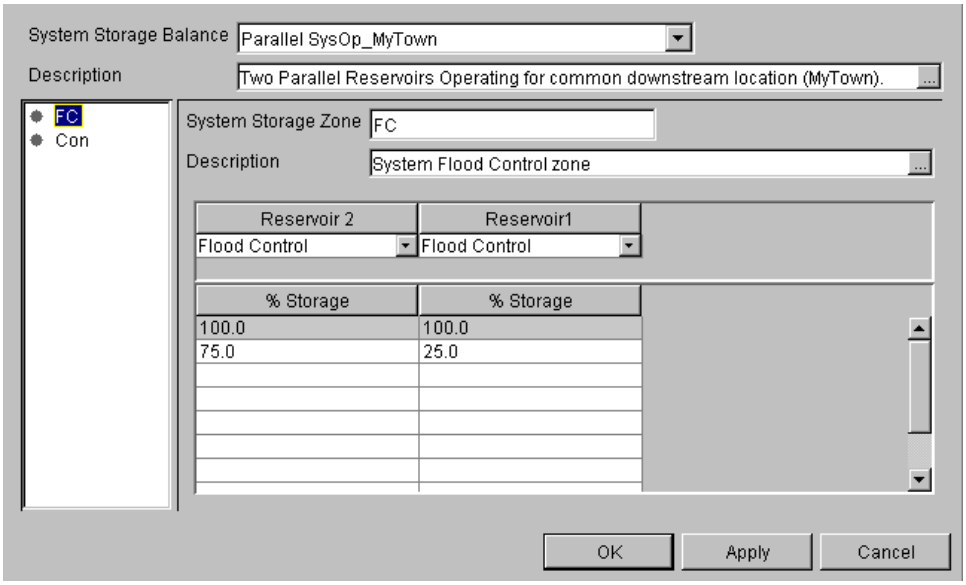

Figure 12.19 Configuring System Storage Balance

1. Choose a **System Storage Balance** option from the drop-down list. Its description will appear in the editable **Description** field, and the available **System Storage Zones** will appear in the white pane on the left side of the editor window.

   

   In Figure 12.19, the **System Storage Balance** field indicates we are using a System Storage Balance called "Parallel SysOp_MyTown," and there are two **System Storage Zones**, "FC" and "Con."

2. Click on a **System Storage Zone** in the white pane on the left side of the editor window to select it. Its name and description will appear to the right in the editable **System Storage Zone** name (as shown below).

   

   In Figure 12.19, "FC" is selected, so its name and description appear in the **System Storage Zone** and **Description** fields.

3. For the selected zone ("FC" in this example), in the list beneath each reservoir name, select a reservoir zone for each reservoir in the system.

   In Figure 12.19, there are two reservoirs in the system and we have chosen the "Flood Control" zone for each reservoir, as shown below:

4. In the table below the reservoir operation sets, enter percentages of system storage zones for each reservoir, as shown in Figure 12.20. These storage percentages represent *inflection points* along the balance line curve, which delineates how the reservoirs will balance when system operations are performed.

% Storage	% Storage
100.0	100.0
75.0	25.0

Figure 12.20 Percent Storage for each Reservoir in a Two-Reservoir System

5. Click **Apply** to save your changes.
6. Repeat the process for each **System Storage Zone** you have created. For example, in Figure 12.19, once you have configured the "FC" System Storage Zone, you would want to configure the reservoir system balance for the "Con" System Storage Zone.
7. If you wish to configure additional storage balance options, click **Apply** to save your changes for the current storage balance option, then select another storage balance option from the **System Storage Balance** list.
8. When you have finished configuring your system storage balance, click **OK** to close the **Reservoir System Editor**.

12.10 General System Operation Notes

As previously discussed, you can allow ResSim to use its implicit storage balance, or you can create an explicit system storage balance. In addition, the following notes related to system operations are provided:

- Empty storage is always zero, while full storage for a reservoir is considered as the maximum storage level in the pool storage-elevation relationship that is defined in the physical tab of the Reservoir Editor.
- For tandem reservoirs, there can be an intermediate control point for which the upstream reservoir operates.
- For parallel reservoirs, the common downstream control rule must be created at only one of the reservoirs and it will automatically be available in the list of existing rules for the other reservoirs. Then, the downstream control rule can be added to the other reservoirs via the "Use Existing" option in the Reservoir Editor (see Chapter 11, Section 11.5.2) in order to establish system operation. If, on the other hand, the downstream control rules are created separately at each reservoir, even if the data entered into the rules are identical, system operation will not be invoked.
- System operation rules can be prioritized along with other rules in the operation set (i.e., depending on prioritization, they may be overridden)
- Guide Curve does not necessarily have to be the top of the conservation zone. The implicit balance scheme will recognize the user setting for a Guide Curve at each reservoir in delineating the default balance lines.
- Implicit and explicit storage balance schemes can be established among two or more reservoirs. When defining an explicit system balance, all reservoirs identified for parallel operation must be included in the reservoir system (refer to Section 12.6). For example, if you have three parallel reservoirs operating for a common downstream location(s), and only two of them are included in an explicit system storage balance, the explicit system storage balance will be ignored and the default implicit storage balance scheme will be used instead.
- The explicit system storage balance is defined using the Reservoir System Editor, as presented in the preceding sections of this chapter. In order to simulate the explicit system operation, the explicit system storage balance must be selected in the Alternative Editor's operations tab along with the reservoir operation sets that contain the system operation rules (refer to Chapter 13, Sections 13.4 and 13.5).